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ANNUAL REPORT

ADVANCED PLANETARY ANALYSES

REPORT NO. SAI-120-A1

END OF YEAR SUMMARY REPORT ON
CONTRACT NASW 2494

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C.

BY

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31 JANUARY 1974

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FOREWORD

This end-of-year Summary Report documents and summarizes the results of all tasks for the entire first year of Contract NASW 2494. It provides a synopsis of all the published and unpublished analysis performed by SAI during the twelve months from 1 February '73 to 31 January '74.

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INTRODUCTION

END OF YEAR SUMMARY
REPORT NASW 2494

ADVANCED PLANETARY ANALYSES

Science Applications, Inc. (SAI) is engaged in a program of advanced study and analysis for the Planetary Programs Office (Code SL) of NASA. The objectives of this study and analysis are to ensure that NASA has an adequate range of viable future planetary mission options compatible with NASA's long range objectives for planetary exploration. The nature of the work is quite varied, ranging from short quick response items to pre-Phase A mission studies. This is an end-of-year Summary Report which documents and summarizes the results of tasks performed over the period 1 February 1973 to 31 January 1974.

The ongoing activities under this contract have been reported to the Planetary Programs Office at four regularly scheduled review meetings. In addition, individual task reports have been prepared and presentations have been made to a wide audience at NASA headquarters and at technical meetings, on the results of individual tasks. Limited quantities of the following reports, annotated presentation brochures and papers are available:

Manpower/Cost Estimation Model for Automated Planetary Projects. SAI-120-C3

Space Shuttle and Planetary Missions (White Paper).

1979 Pioneer Mars Missions. SAI-120-M1

A Comparison of Advanced Propulsion Capabilities for Future Planetary Missions (AIAA 73-587).

Measurement Error Analysis in Determination of Small Body Gravity Fields (AIAA 74-218).

Comet Encke Fly-by with Asteroid Rendezvous Mission (in press-Journal of Spacecraft and Rockets).

Advanced Planning Activity Summary Report SAI-120-M2.

The following sections summarize the results of the three contract tasks relating to cost estimation research, the planetary missions handbook and advanced planning activities, respectively. The total value o the contract was $169, 000 and included a scheduled effort of 5976 man-hou The distribution of the effort is indicated in each task summary.

COST ESTIMATION RESEARCH

1. Cost Estimation Research. (13 Man Months)

The purpose of this task is to continue the development of the planetary spacecraft cost estimation model which had been started under a previous NASA contract. Two major functions have been performed in that the financial data base has been extended and reorganized considerably and the labor estimation relationships (LERs) in the estimation model have been completely revised. The manpower/cost estimation model now developed incorporates two significant improvements on past practice. First it is based on a detailed level of financial analysis of over 30 million raw data points which are then compacted by over three orders of magnitude to the level at which the model is applicable. Second the major parameter of expenditure is manpower (specifically direct labor hours) for all spacecraft subsystem and technical support categories. The resultant model, which is applicable at a pre-Phase A project level is able to provide a mean absolute error of less than ten percent for the eight programs comprising the model data base.

The cost data used for the model was in a form that permitted analysis below the subsystem level and allowed for the adjustment of subsystem definitions to ensure compatibility among different projects. The data profile consisted of a financial breakdown structure which listed cost accounts associated with a given spacecraft cost element. Such accounts generally consisted of wages, salaries, rental services, tooling, material purchases, etc. Data was then acquired on the direct labor hours (DLH) charged to each spacecraft cost element by engineers, scientists, technicians, administrative and manufacturing personnel, and clerical workers. One recognizes that direct labor hours and direct labor dollars are essentially perfectly correlated in each cost element via the appropriate wage rate.

Raw data obtained over the eight projects consisted of 648 financial categories and 4843 spacecraft cost elements spread across 327 prime and subcontracts. In total, some 11.5 million expenditure items were examined. These accounted for 99.7% of the actual total of $1.65 billion expenditures for the eight projects (Surveyor, Lunar Orbiter, Mariner '64, '69, '71, Pioneer F/G, Viking Lander and Orbiter). Additional data is being collected for atmospheric probes and is being used to recalibrate the estimation relationships.

The most immediate result of this analysis was the considerable insight it gave into where the money is actually spent in a space project. In addition however, it was recognized that the rigidity of the government accounting system in fact was extremely beneficial in analyzing data over a range of projects spanning one and a half decades in time. The common denominator of the NASA cost reporting system is the cost incurred in direct labor hours (DLH) which is typically 30% of the total project cost. It is from this base that the allowable overhead, G & A, and fee are computed by preset ratios. The category of other direct costs (ODC), typically 15% of the total project costs, is a secondary denominator for costs actually incurred in a project. In fact, these two, DLH & ODC, are the only two categories by which a contractor can claim payment for his work on a project. Because direct labor hours, with ODC's, are the only parameters used to express the investment of time and materials in the spacecraft, and because they are so uniformly reported, then they should be directly related to the overall cost of the project.

Forecasting manhours has several distinct advantages over directly forecasting total project dollars. Among these are separation of estimates from inflation factors and an ease in costing low volume production. Inflationary factors are difficult to formulate for total project costs and often fail to represent accurately actual financial conditions within the industry. The space industry has not yet been able to use mass production techniques and thus the total cost of each completed item is not substantially decreased through additional production. Hence, project hardware cost is directly related to the manhours involved in development, fabrication and testing. The present average direct labor ratio is 29.6% with a standard deviation of 0.5%. Also, the effect of learning and inheritance can be analyzed and measured more easily in terms of manpower requirements.

The division between non-recurring and recurring direct labor is not uniquely definable. However, the analysis has identified the completion date of the Proof Test Model (PTM) to be the best demarcation point for this division of labor. The PTM is a clearly defined point in a project, particularly from a historical standpoint. It is at least plausible that about as much recurring cost is incurred before the PTM as non-recurring cost after the PTM since work on the first flight article begins near the time of PTM acceptance. Hence, for the purpose of modeling, the PTM represents a very good project milestone marking the transition from non-recurring to recurring manpower.

In using the extended and modified manpower and financial data base to reconstruct the cost estimation model, several requirements were identified:

i) The input parameters should be consistent with (pre) Phase A definition of subsystems and mission operations, e.g., weight, power, event times, etc.

ii) The functional form of LER's should be simple algebraic expressions, e.g., linear, power law, exponential.

iii) The number of coefficients in a given LER should be limited to improve statistical significance of data fit.

iv) The LER should derive from an unbiased regression analysis, i.e., the balancing of plus and minus errors to yield a near-zero mean error.

In addition, two basic premises should always be kept in mind by the cost analyst or the user of the estimation model:

- A cost model does not represent "truth" but only a simplified, empirical approximation to actual cause and effect.
- Due to the phenomena of averaging, total project cost will be more accurately estimated than individual elements when viewed from a statistical standpoint of percentage error.

A correlary to the averaging premise is, of course, that reduction of variance of fit in individual elements will further reduce error variance in total cost.

The cost estimation model uses 21 spacecraft/mission parameters which, for the most part, are weights of key subsystem elements. Nonwithstanding the desire to model on the basis of performance parameters, weight has been a meaningful composite parameter that correlates fairly well with design/ development complexity and effort. In this sense the present approach is not unlike earlier cost estimation models. Regarding the question of statistical significance, the ratio of total data points to the total number of model coefficients is approximately 3 to 1. By analogy this is akin to fitting a straight line (or power function) through 6 data points. The 21 model inputs are given in Table 1.1. The labor estimating relationships are given in Table 1.2.

The two additional parameters needed to convert direct labor hours into total project cost are the wage rate (\$/hr.) and the percentage of project dollars invested in labor. The wage rate can be modeled on the basis of historical data and the model can be used for extrapolation purposes within careful limitations. In pursuing the modeling approach, it was found that by taking the fiscal year date at which funding reached the 50% level one could obtain an accurate conversion of manhours to actual dollar expenditure. A regression analysis applied to all eight projects resulted in the following equation for average rate across all project categories.

$$\text{Wage Rate (\$/hr.)} = 4.67\ (1.0513)^{(MY-1964.5)}$$

where MY is the median fiscal date for a given project. This expression represents an average 5.13%/year inflation rate over the last decade which is also typical of the general economy. The accuracy of fit is measured by a standard deviation of only 19¢/hr.

TABLE 1.1

Cost Model Inputs

TL	Date of First Launch (Calendar Yr.)
TM	Fiscal Year for Dollar Values
NFA	Number of Flight Articles
WSI	Total Weight of Structure Subsystem (lbs.)
WS2	Weight of Mechanisms and Landing Gear (lbs.)
WS3	Weight of Thermal Control Pyro and Cabling (lbs.)
WP1	Propulsion System Dry Weight Excluding Throttable Liquid Vernier for Landers (lbs.)
WP2	Liquid Vernier Dry Weight (lbs.)
WP3	Aerodeceleration Subsystem Weight (lbs.)
WG1	Total Weight of Guidance/Control Subsystem (lbs.)
WG2	Weight of Radar in G/C Subsystem (lbs.)
WC1	Weight of Radio Frequency Comm. Subsystem (lbs.)
WC2	Weight of Data Handling Subsystem (lbs.)
WC3	Weight of Antennas
WEP1	Weight of Power Subsystem Excluding RTG's (lbs.)
NU	Number of RTG Units per Spacecraft
FL	RTG Fuel Loading (Thermal Watts)
WSE1	Total Weight of Science Experiments (lbs.)
WSE2	Weight of Lander Surface Experiments in WSE1 having Significant Sampling/Processing Operations (lbs.)
PPL	Pixels per Line of TV (or equivalent visual imaging)
PU	RTG Unit Power-End of Life (Watts)
INHER	15 Inheritance Factors, Values between 0 (No Inheritance) and 1.0 (Maximum Inheritance)

TABLE 1.2

LER's For Spacecraft Subsystem Categories

Structure

$$\begin{array}{ll} \text{Non-Landers} & \left\{ \begin{array}{l} NR_{ST} = 6.68\,(WS2)^{0.691} + 11.9\,(WS3)^{0.507} + 28.4\,(WS1-WS2-WS3)^{0.427} \\ NR_{ST} = 1.35\,WS2)^{1.35} + 11.9\,(WS3)^{0.507} + 28.4\,(WS1-WS2-WS3)^{0.427} \end{array} \right. \\ \text{Landers} & \end{array}$$

$$R_{ST} = 0.109\,(NFA)\,(NR_{ST})$$

Propulsion

$$NR_{P} = 21.6\,(WP1)^{0.5} + 34.1\,(WP2)^{0.5} + 14.4\,(WP3)^{0.5}$$

$$R_{P} = 0.148\,(NFA)\,(NR_{P})$$

Guidance and Control

$$NR_{GC} = 17.8\,(WG1)^{0.722} + 69.6\,(WG2)^{0.607}$$

$$R_{GC} = 0.138\,(NFA)\,(NR_{GC})$$

Communications

$$NR_{C} = 7.70(WC1) + 23.0\,(WC2)^{0.670} + 17.0\,(WC3)^{0.5}$$

$$R_{C} = 0.180\,(NFA)\,(NR_{C})$$

Power

$$NR_{EP} = 0.643\,(WEP) + 152$$

$$R_{EP} = 0.150\,(NFA)\,(NR_{EP})$$

Science Experiments

$$NR_{SE} = 0.110\,(PPL) + 1.56\,(WSE1) + 12.1\,(WSE2) + 220$$

$$R_{SE} = 0.237\,(NFA)\,(NR_{SE})$$

TABLE 1.2 (Cont'd.)

LER's For Technical Support Categories

DLH_{SS} = Total direct labor hours of all subsystem categories. (in thousands of hours)

Program Management

$$DLH_{PM} = 94\, e^{2.83 \times 10^{-4}\, DLH_{SS}}$$

Systems Analysis and Engineering

$$DLH_{SAE} = 1.94 \times 10^{-8}\, (DLH_{SS})^{2.76}$$

Test and Quality Assurance/Reliability

$$DLH_{T} + DLH_{QAR} = 226\, e^{2.82 \times 10^{-4}\, DLH_{SS}}$$

Assembly and Integration

$$DLH_{AI} = 7.82 \times 10^{-4}\, (DLH_{SS})^{1.47}$$

Ground Equipment and Launch/Flight Operations

$$DLH_{GE} + DLH_{LFO} = 1360\, T^{-0.392}\, e^{1.73 \times 10^{-4}\, DLH_{SS}}$$

Where T = Launch Date - 1960.6

A model is being developed for inheritance as indicated in Figure 1.1. The major distinction made in modeling inheritance is whether or not there is any impact on the research and development component of the cost of a subsystem. Large savings are only achieved if this non-recurring cost component can be reduced. The extreme case of inheritance is one of adding a flight article to a project in which case the non-recurring cost assigned to the additional flight article is zero.

The complete model has been programmed for use with a mini-computer located in the SAI offices (Hewlett-Packard 9830) so that very short turn around times can be achieved. A typical output is shown in Figure 1.2 which lists:

1) the 21 input parameters
2) the computed average wage rate and labor percentage
3) the computed direct labor hours and cost for thirteen categories
4) the computed total cost of the project for two flight articles
5) the computed cost for additional flight articles
6) the estimated RTG costs
7) the computed cost spread for 4 and 5 years.

It should be noted that the project data base modeled does not include contractor fee, NASA Headquarters and Center management cost, or launch vehicle cost. This may explain any reconciliation between the "actual" costs listed and the reader's mental recognition of slightly different numbers. The initial goal of 10% average error has been met. Out of the 8 projects, 4 are estimated within 5% while 7 projects are estimated within 12%. Since Surveyor represented the most complex unmanned space project undertaken in the early 1960's, and derived essentially zero inheritance from previous experience, it is not too surprising that the present model underestimates its cost by 35%.

A final result of interest is the distribution of cost element errors itemized by project and category. Figure 1.3 summarizes this data in the form of a statistical histogram. The density function has a fairly sharp spike

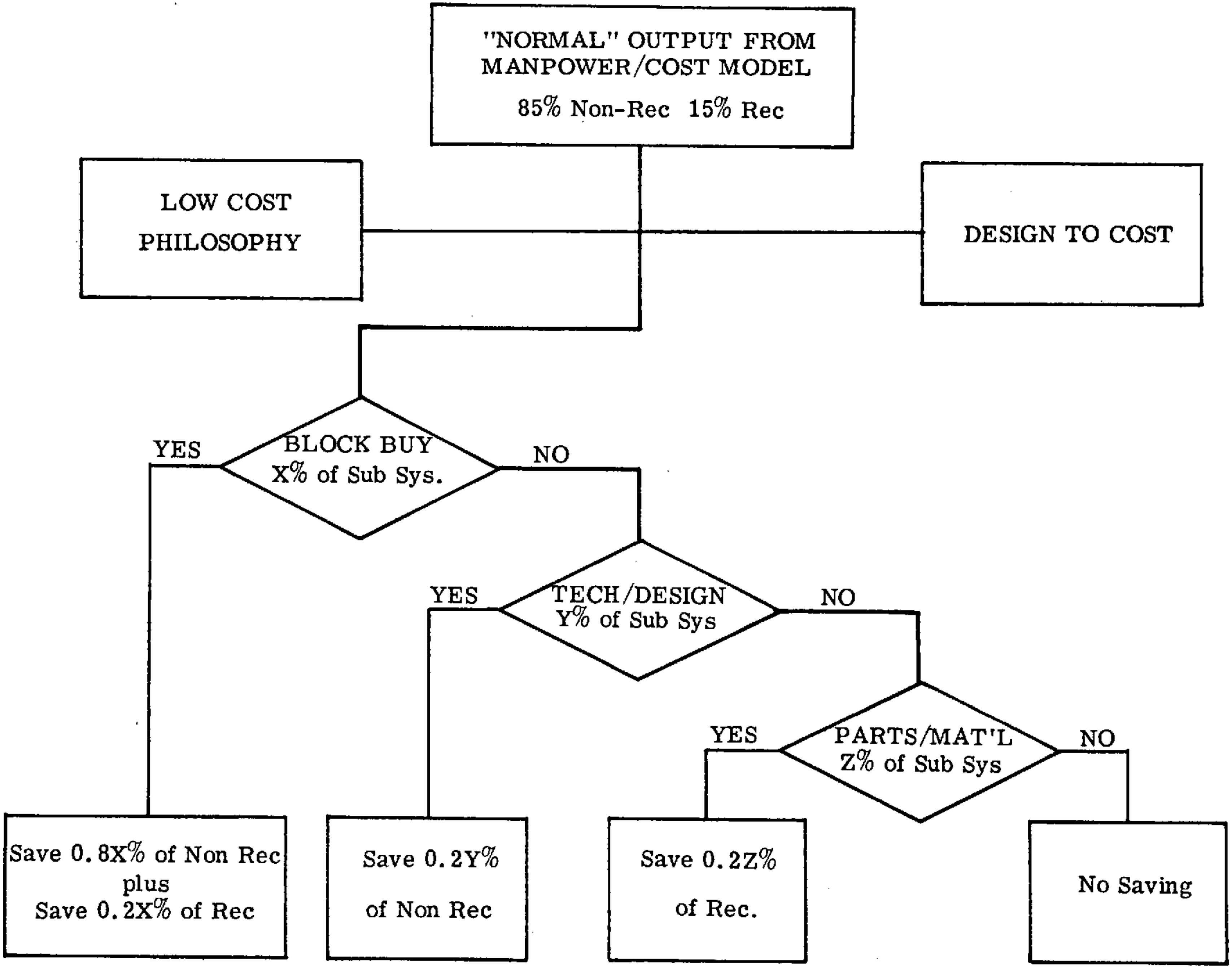

FIGURE 1.1 LOGIC FOR INHERITANCE COST SAVINGS

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PROJECT NAME    SAMPLE OUTPUT FOR ANNUAL REPORT    120-A-1

PROJECT DESCRIPTION   WEIGHT UNITS(POUNDS),POWER UNITS(WATTS)
LAUNCH DATE (D1)        1985.1    TOTAL STRUCT. WT(S1)     427.0     G/C RADAR WT (G2)          0.0
FISCAL WAGE DATE(D2)    1974.0    MECHANISMS/LG WT(S2)      50.0     RADIO COMM. WT (C1)      155.0
FLIGHT ARTICLES (N1)       2.0    TC PYRO.CABL.WT (S3)     115.0     DATA HANDLING WT(C2)     121.0
NON-RTG POWER WT(W1)     110.0    PROP.SYS DRY WT (P1)     427.0     ANTENNA WT (C3)           50.0
RTG UNIT PER S/C(N2)       4.0    VERNIER DRY WT (P2)        0.0     TOTAL SCIENCE WT(Q1)     160.0
RTG EOL UNIT PWR.(U)     125.0    AERODECEL WT (P3)          0.0     SURF. SCIENCE WT(Q2)       0.0
RTG FUEL LOADING(L1)    2200.0    TOTAL G/C WT (G1)        209.0     PIXELS/LINE (TV)(Q3)    1500.0

INHERITANCE %                          STR       PROP       G/C       COMM       POW       SCI
EXACT REPEAT(BLOCK BUY)                25%        25%       25%        50%       50%       25%
TECHNOL/DES(NON-IDENTICAL S/C)         75%        75%       65%        50%       50%       50%
PARTS,COMPONENTS,MATERIALS              0%         0%        0%         0%        0%        0%
-----------------------------------------------------------------------------------------------

                                      COST          DIRECT LABOR      NON-RECURRING       RECURRING
                                   (MILLIONS)        (000 HRS)          (000 HRS)         (000 HRS)
SUBSYSTEM CATEGORIES             NORM     INHER     NORM    INHER     NORM    INHER     NORM    INHER
     STRUCTURE                   16.6     11.7       655     461       538     350       117     111
     PROPULSION                  14.7     10.5       578     416       446     290       132     126
     GUIDANCE AND CONTROL        27.3     19.9      1074     785       842     564       232     221
     COMMUNICATIONS              65.1     39.4      2564    1554      1885     943       679     611
     POWER                        7.3      4.4       290     172       223     111        67      60
     SCIENCE                     23.7     18.5       935     730       634     444       301     286

        SUBTOTAL                154.7    104.5      6097    4116      4569    2702      1528    1414

SUPPORT CATEGORIES
    PROGRAM MANAGEMENT           13.4       7.6      528      301
    SYSTEMS ANALYSIS/ENG.        13.8       4.7      543      184
    TEST + QUALITY ASSURANCE     32.0      18.3     1261      721
    ASSEMBLY AND INTEGRATION      7.3       4.1      287      161
    GROUND EQUIP.+ FLIGHT OPS.   28.3      20.1     1114      791

        SUBTOTAL                 94.7      54.8     3733     2158
***********************************************************************************************
        TOTAL (WITHOUT RTG)     249.4     159.2     9829     6275                RTG COST =     11.8

        TOTAL                   261.3     171.1                        ADDL. FLIGHT UNIT =     43.1
***********************************************************************************************
FISCAL YEAR       1982        1983        1984        1985        1986        1987
5 YEAR SPREAD    25.23       45.63       49.00       59.35       51.19       17.79
4 YEAR SPREAD     0.00       29.49      100.73       83.95       32.44        1.40
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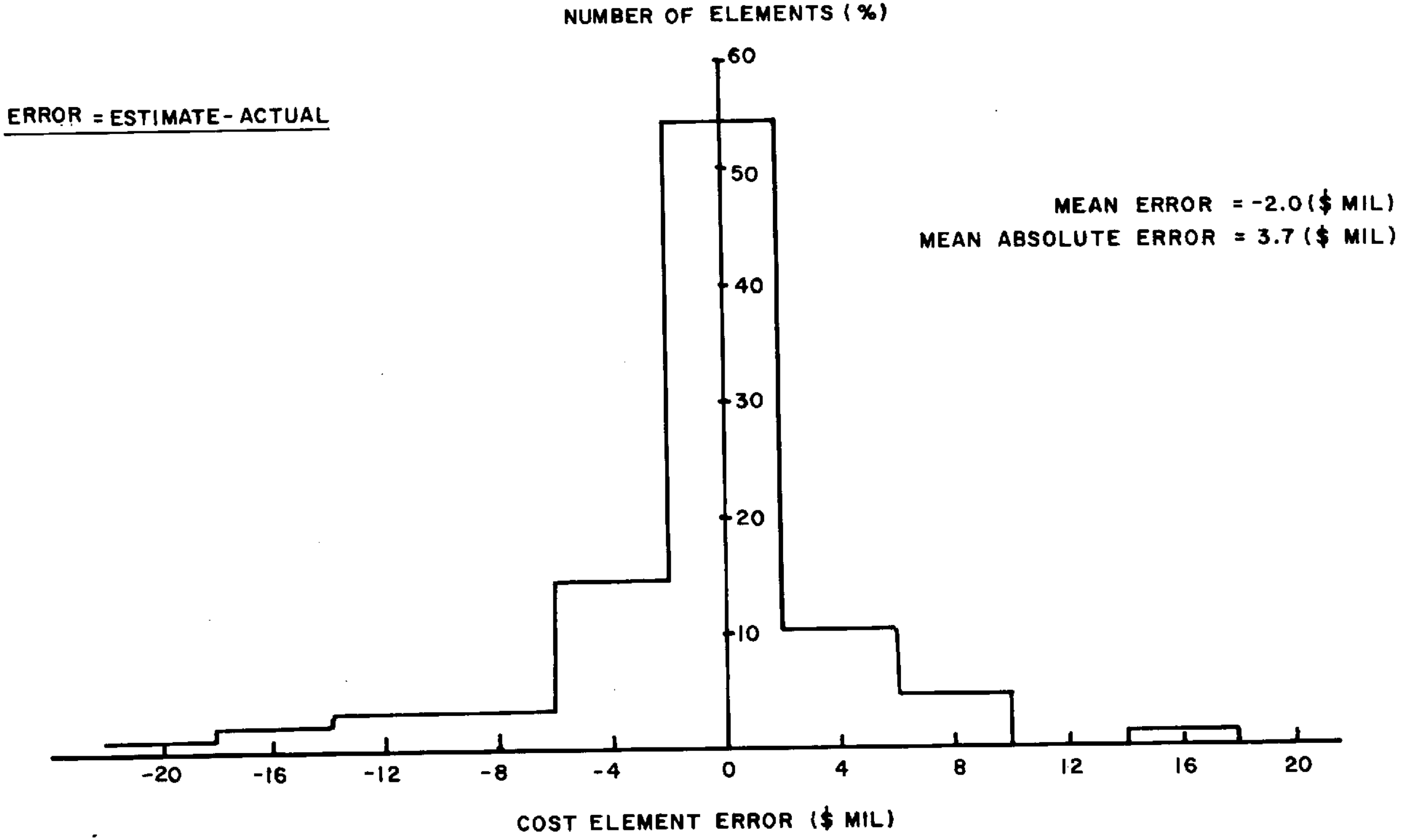

FIG. 1.3 DISTRIBUTION OF ESTIMATION ERRORS FOR 88 COST ELEMENTS
(11 CATEGORIES X 8 PROJECTS)

centered around zero error but the tailoff is less rapid than would be desired. Estimation errors associated with Surveyor are mainly responsible for the long tailoff and the negative bias in the distribution. The mean error and mean absolute error taken over the other 7 projects are, respectively, -$0.4 million and $2.3 million.

PLANETARY MISSION HANDBOOK

2. Planetary Missions Handbook (5 Man Months)

The purpose of the Planetary Missions Handbook is to provide NASA mission planners with basic planetary, opportunity dependent, performance data. A high priority has been placed on the use of the Handbook as a ready source of data and thus we have emphasized its clarity, organization and ease of usage.

A first edition has been produced on a previous NASA contract and is in the form of a compilation of graphs - 80 in all. The work performed under this contract relates still to the outer planets but extends the opportunities to 1990 and includes multiple swing-by missions. Further, although launch vehicle performance curves are an important part of the Handbook, they are supplemented by tables of data which allow much easier interpolation. In the course of the development of the Handbook data we have developed an effective computational scheme for use with our in-house minicomputer (Hewlett-Packard 9830), so that where more accurate data is required than can be provided by interpolation, we can provide a quick response analytical capability.

Basic trajectory data has had to be computed for all added missions, using the SPARC computer program, because the NASA Special Publication SP-35, used as a source for the first edition, does not go beyond 1986. The SEP data has all been generated using the CHEBYTOP Computer Program.

The planetary missions to be included in the handbook are shown in Table 2.1 with the departure and orbit capture propulsion assignments. Since SEP trajectory data is relatively expensive to generate, launch window data has been restricted to a single, median opportunity for each of the four outer planet SEP missions. The results are used to measure performance degradation in terms of payload loss as a function of launch window size. This degradation (typically 5%) will be applied, with acceptable accuracy, over the other launch opportunities for each mission type. A single nuclear electric mission for a Uranus Orbiter is also included.

TABLE 2.1

PLANETARY MISSIONS HANDBOOK PROPULSION ASSIGNMENTS

Missions	Propulsion System Application	Calendar Launch Year														
		76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Jupiter Flybys and Orbiters	Launch	CRP	CRP	CRP	CRP	CRP	CRP		CRP	CRP	CRP	CRP	CRP	CRP	CRP	CRP
	Orbit Capture	ESR	ESR	ESR	ESR	ESR SSR	ESR SSR		ESR SSR	ESR SSR	ESR SSR	ESR SSR	ESR SSR	ESR SSR	ESR SSR	ESR SSR
Saturn Flybys and Orbiters	Launch & Transfer	CRP	CRP	CRP	CRP	CRP SEP	CRP SEP	CRP SEP		CRP SEP	CRP SEP GSEP	CRP SEP GSEP	CRP SEP GSEP	CRP SEP GSEP	CRP SEP GSEP	CRP SEP GSEP
	Orbit Capture	ESR	ESR	ESR	ESR	ESR SSR	ESR SSR	ESR SSR		ESR SSR	ESR SSR	ESR SSR	ESR SSR	ESR SSR	ESR SSR	ESR SSR
Uranus Flybys and Orbiter	Launch & Transfer					CRP SEP					CRP SEP GSEP					CRP SEP GSEP NEP
	Orbit Capture					ESR SSR					ESR SSR					ESR SSR
J/U/N Swingbys	Launch & Transfer				CRP SEP	CRP SEP	CRP SEP									
S/U/N Swingbys	Launch & Transfer					CRP SEP	CRP SEP	CRP SEP		CRP SEP	CRP SEP					

NOMENCLATURE: CRP - Chemical Rocket Propulsion; SEP - Solar Electric Propulsion (20KW), GSEP - (40KW);
NEP - Nuclear Electric Propulsion (120KW); ESR - Earth Storable Retro (Isp = 285 SEC);
SSR - Space Storable Retro (Isp = 375 SEC)

The propulsion options to be presented for all missions used in the Handbook are shown in Table 2.2 as a function of launch year. Up until 1980, before the Shuttle is available, only one launch vehicle is used, between 1980 and 1984 a total of eight options are available and beyond 1985 six options are considered. However, since the time when this list was approved by NASA, there has been a series of interagency (NASA/DOD) discussions aimed at developing a common OOS stage as an intermediate Tug (see Advanced Planning Task Number 14). Since generation of mission performance data for the Handbook is awaiting the publication of the 1974 edition of the Launch Vehicle Estimating Factors Handbook, it is intended that the second through eighth launch vehicles in Table 2.2 be reviewed with NASA at that time. The performance of a final set of launch vehicle selections will be incorporated into the final data run.

For Jupiter, Saturn and Uranus orbiter missions, orbit payload performance tables will be provided in addition to the standard payload versus flight time performance curves. An example of this is shown in Table 2.3 for a ballistic 1981/82 Jupiter Orbiter mission. Launch and retro specifications are at the top of Table 2.3. The first section of the table contains net useful payload in-orbit data for a range of orbit periods (15, 30 and 60 earth days), a range of flight times (500 - 900 earth days) and a range of periapse distances measured in planet radii from the center of the planet. The second section gives the associated total retro mass for the same range of orbit periods, flight times and periapse distances. The retro mass assumes a rubber tank and is included to indicate the gross weight distribution between the retro and the payload as it approaches the planet. Interpolation is possible for intermediate orbit periods, flight times, and periapse distances. For each launch opportunity, one such table is included per launch vehicle/retro combination. In addition, one graph is included showing curves of payload versus flight time for all launch vehicle selections, for one orbital period and periapse distance.

TABLE 2.2

PLANETARY MISSIONS HANDBOOK LAUNCH/TRANSFER PROPULSION AVAILABILITY

PROPULSION SYSTEMS	1976	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1. TITAN IIIE/CENTAUR/TE 364-4*	━	━	━	━	━	━	━	━	━						
2. TITAN IIIE/CENTAUR/SEP(20KW)					━	━	━	━	━						
3. SHUTTLE/CENTAUR/TE 364-4					━	━	━	━	━						
4. SHUTTLE/CENTAUR/SEP(20KW)					━	━	━	━	━						
5. SHUTTLE/ITUG(E)/TE 364-4					━	━	━	━	━	━					
6. SHUTTLE/ITUG(E)/SEP(20KW)					━	━	━	━	━	━					
7. SHUTTLE/ITUG(R)/KICK(APC)					━	━	━	━	━	━					
8. SHUTTLE/ITUG(R)/KICK(APC)/SEP(20KW)					━	━	━	━	━	━					
9. SHUTTLE/TUG(E)/TE 364-4											━	━	━	━	━
10. SHUTTLE/TUG(E)/SEP(20KW)											━	━	━	━	━
11. SHUTTLE/TUG(E)/GSEP(40KW)											━	━	━	━	━
12. SHUTTLE/TUG(R)/KICK(APC)											━	━	━	━	━
13. SHUTTLE/TUG(R)/KICK(APC)/SEP(20KW)											━	━	━	━	━
14. SHUTTLE/TUG(R)/KICK(APC)/GSEP(40KW)											━	━	━	━	━

*TE 364-4 ADDED ON REQUIRED BASIS THROUGHOUT

TABLE 2.3

JUPITER ORBITER MASS PERFORMANCE

LAUNCH OPPORTUNITY	1981/82
LAUNCH WINDOW	21 DAYS
LAUNCH VEHICLE	SHUTTLE/CENTAUR/BURNERII(2300)
RETRO SYSTEM	EARTH STORABLE(ISP=290 SEC)
EXCESS DV	250 M/SEC

ORBIT PERIOD	TRANSFER TIME		NET USEFUL PAYLOAD (KG)						
(DAYS)	(DAYS)	(YRS)	RP=1.1	RP=2	RP=3	RP=4	RP=6	RP=8	RP=10
15.00	500	1.37	268	158	85	37	0	0	0
15.00	600	1.64	597	446	338	260	152	79	25
15.00	700	1.92	856	693	570	479	345	250	177
15.00	800	2.19	1007	847	722	628	486	382	300
15.00	900	2.46	987	842	728	640	508	409	330
30.00	500	1.37	308	200	127	77	13	0	0
30.00	600	1.64	671	530	427	352	244	170	115
30.00	700	1.92	956	813	702	617	491	399	327
30.00	800	2.19	1122	987	879	795	668	571	494
30.00	900	2.46	1099	979	883	808	691	602	529
60.00	500	1.37	335	229	156	106	40	0	0
60.00	600	1.64	721	589	490	417	312	238	182
60.00	700	1.92	1024	895	793	715	597	509	440
60.00	800	2.19	1200	1083	989	914	800	712	641
60.00	900	2.46	1175	1074	991	926	824	744	680

ORBIT PERIOD	TRANSFER TIME		TOTAL RETRO MASS (KG)						
(DAYS)	(DAYS)	(YRS)	RP=1.1	RP=2	RP=3	RP=4	RP=6	RP=8	RP=10
15.00	500	1.37	708	818	891	939	0	0	0
15.00	600	1.64	824	975	1083	1161	1269	1342	1396
15.00	700	1.92	837	1000	1122	1214	1348	1443	1516
15.00	800	2.19	809	969	1093	1188	1330	1434	1516
15.00	900	2.46	733	878	992	1080	1212	1311	1390
30.00	500	1.37	668	776	849	899	963	0	0
30.00	600	1.64	750	890	994	1069	1177	1251	1306
30.00	700	1.92	737	880	991	1076	1202	1294	1322
30.00	800	2.19	694	829	937	1021	1184	1245	1322
30.00	900	2.46	621	741	837	913	1029	1118	1191
60.00	500	1.37	641	747	820	870	936	0	0
60.00	600	1.64	700	832	931	1004	1109	1183	1239
60.00	700	1.92	669	798	900	978	1096	1184	1253
60.00	800	2.19	616	733	227	902	1016	1104	1175
60.00	900	2.46	545	646	729	794	896	975	1040

The assemblage of the various sections of the Handbook is shown in Figure 2.1. It is organized by mission type. Within each type, a table of opportunities is included. For each opportunity the appropriate performance graphs and tables are presented. Thus the ordering system maximizes the users ability to find directly the information of interest.

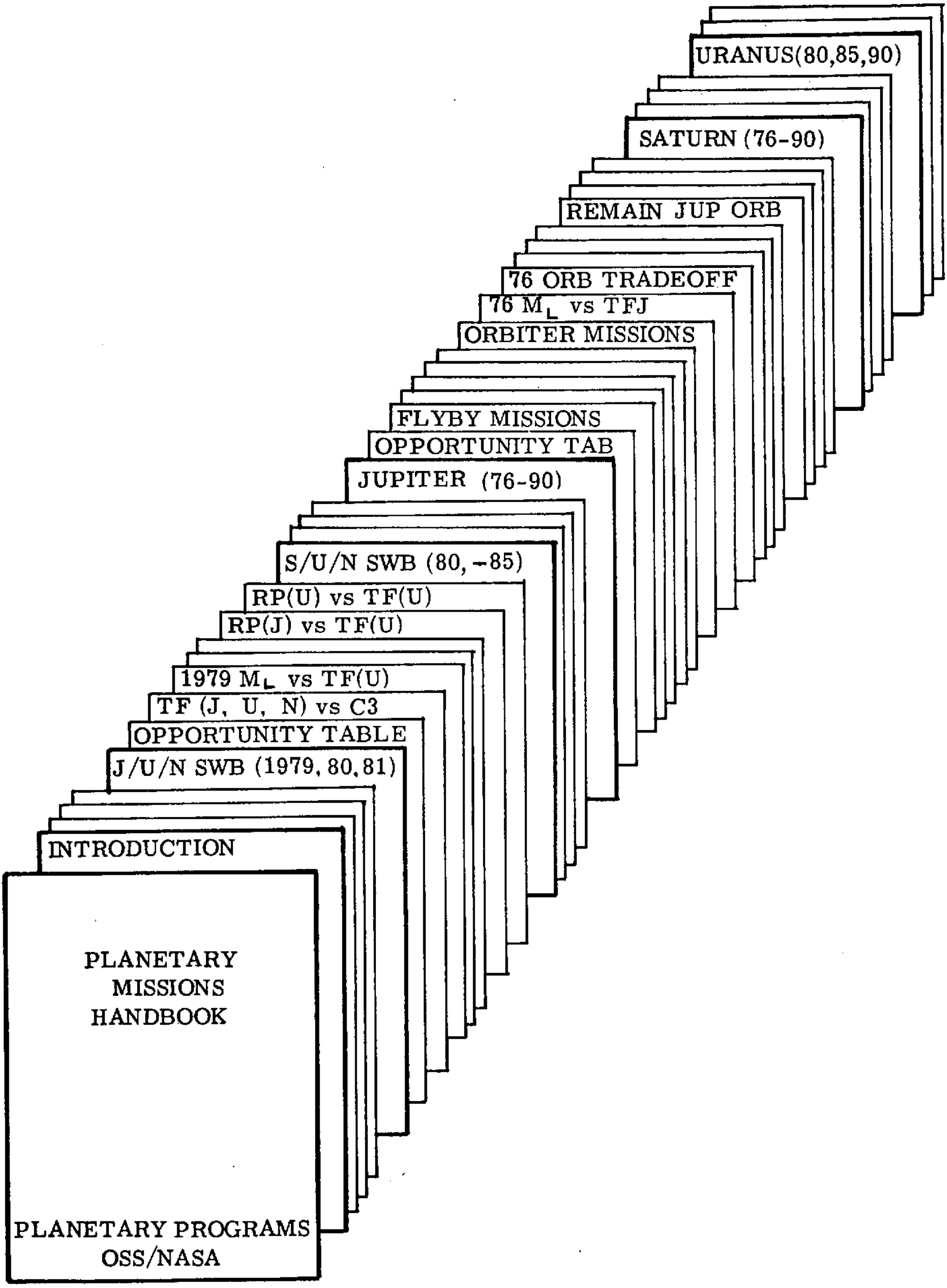

FIGURE 2.1 PLANETARY MISSIONS HANDBOOK LAYOUT (2ND EDITION)

ADVANCED PLANNING ACTIVITY

3. Advanced Planning Activity (19 Man Months)

This task area has been a focal point for the day-to-day interaction between NASA Planetary Programs Office and the SAI staff. Unscheduled fast response jobs have been a normal part of this task area throughout the contract year and in all cases the required response has been met. The tasks have varied from straight forward exchanges of technical data by phone, to short one or two page responses transmitted by mail or telecopier, to more significant memoranda and finally to mini-mission studies. The effort expended per task has varied from approximately one hour to almost six man-months. This report summarizes a total of 17 of the more significant advanced planning analyses, all of which were the subject of written submissions at the time they were completed. Table 1 gives a summary of these advanced planning tasks.

1. Jupiter Orbiter Performance Comparison - Earth Storable versus Space Storable Retro Propulsion

The orbited payload capability was examined for three Jupiter opportunities - 1980, 1981/82 and 1983. Payload performance was evaluated as a function of flight time to Jupiter using Titan III E/Centaur/B II and Shuttle/Centaur/B II launch vehicles. A 30-day orbit with periapse at $3R_J$ was assumed in the analysis. It was concluded that space-storable retro propulsion provides from 75 to 100 kg more orbit payload than earth-storable propulsion when combined with the Titan III E/Centaur/B II during the three opportunities examined. Using the Shuttle/Centaur/B II this advantage with space storable propulsion increases to about 150 kg. It was further concluded that the combination of the Titan launch vehicle with an earth-storable retro propulsion system is marginal for MJO missions. The Shuttle launch vehicle has sufficient additional capability to rate MJO missions for the period 1980 - 83 as acceptable with earth storable retro propulsion.

Table 1.

SUMMARY OF ADVANCED PLANNING ACTIVITY

TASK	DATES	TASK TITLE	SUBMITTED TO
1.	FEB. '73	Jupiter Orbiter Performance Comparison - Earth Storable versus Space Storable Retro Propulsion	NASA HQ.
2.	FEB. '73	Jupiter Orbiter Performance Depth with Fixed and Expanded MM '71 Retro Propulsion Subsystems	JPL
3.	FEB. - MAY '73	1983 Venus and 1986 Uranus/Neptune SEP Missions	MSFC/RI
4.	FEB. - MAY '73	1989 Venus and 1981/82 Encke Rendezvous SEP Missions	MSFC/RI
5.	MAR. - MAY '73	1989 Saturn and 1989 Asteroid (METIS) Rendezvous SEP Missions	MSFC/RI
6.	MAR. - MAY '73	1987 Mercury SEP Mission	MSFC/RI
7.	MAR. - MAY '73	Space Shuttle and Planetary Missions	NASA HQ.
8.	APRIL - MAY '73	Pioneer Saturn and Uranus Entry Probe Mission Dates	NASA HQ. /OPSAC
9.	MAY '73	Comet Kohoutek Fly-By Mission Parameters	NASA HQ.
10.	JUNE '73	Recovered Tug Earth Escape Performance	MSFC
11.	JULY - NOV. '73	Titan Atmosphere Workshop	ARC /NASA HQ.
12.	OCT. '73	Inputs for Electric Propulsion Conference	NASA HQ.

SUMMARY OF ADVANCED PLANNING ACTIVITY (Cont'd.)

TASK	DATES	TASK TITLE	SUBMITTED TO
13.	OCT. '73	1985 Saturn Orbiter Performance Curves	NASA HQ.
14.	OCT. - DEC. '73	OOS Tug Evaluation	NASA HQ.
15.	NOV. '73	Ballistic Rendezvous with Encke 81/82	NASA HQ.
16.	NOV. '73	Comet Encke 80 Fly-By - Asteroid Rendezvous Mission	NASA HQ.
17.	NOV. - JAN. '73	Pioneer Mars 1979 Mission Options	NASA HQ. / ARC

2. Jupiter Orbiter Performance Depth with Fixed and Expanded MM '71 Retro Propulsion Subsystems

The total burnout mass capability of a Jupiter orbiter was examined with a MM '71 retro propulsion subsystem. The analysis was restricted to an 800-day mission launched during the 1981/82 Jupiter opportunity. Both the Titan IIIE/Centaur/BII and Shuttle/Centaur/BII launch vehicles were considered. The purpose of this analysis was to investigate the performance depth of the MM '71 retro propulsion subsystem design. Depth of performance was measured by the ability of the retro system to deliver acceptable orbiter burnout mass to a fixed period 30-day orbit with increasing periapse radius. Results were presented which showed that less than 600 kg was available for the orbiter (exclusive of the propulsion subsystem) for all orbit periapse radii greater than 2 R_J if the Titan IIIE/Centaur/BII was used for launch. The same conclusion applies to a Shuttle/Centaur/BII launched mission if the propellant capacity is limited by the present MM '71 tank size. However, by increasing the propellant capacity the orbit periapse radius can go as high as 6.75 R_J before the net orbiter mass (excluding the propulsion subsystem) falls below 600 kg. The required propellant capacity at this point would be approximately 2.25 times as large as that of the present design. From this brief analysis it was concluded that acceptable application of the MM '71 retro propulsion system to an MJO mission would almost certainly require expanded propellant capacity. Doubling the tankage, i.e. four tanks instead of two, combined with Shuttle/Centaur/BII launches would provide considerable propulsion flexibility for MJO mission planning.

3. 1983 Venus and 1986 Uranus/Neptune SEP Missions

Data was generated for a 20 kw SEP stage for both missions and also a 15 kw stage for the Venus Mission. Three launch vehicles were considered: Shuttle/Tug (I, R)*/SEP, Shuttle/Tug (I, R)/Kick/SEP and

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*(I, R) = intermediate, reusable.

and Shuttle/Centaur/SEP. For each option the initial mass,propellant mass and net approach mass were provided as a function of flight time. The analysis was performed as an input to a study being performed by Rockwell International for Marshall Space Flight Center.

4. 1989 Venus and 1981/82 Encke Rendezvous Missions

Data was generated for a 20 kw SEP stage for both missions. Three launch vehicles were considered: Shuttle/TUG (I, R)/SEP, Shuttle/Tug (I, R)/Kick/SEP and Shuttle/Centaur/SEP. For each option the initial mass, propellant mass and net approach mass were given as a function of flight time. In addition, for Encke rendezvous, SEP propulsion times between 750 and 1100 days were considered.

5. 1989 Saturn and 1989 Asteroid (METIS) Rendezvous SEP Missions

Data was generated for a 20 kw SEP stage for both missions. For the Saturn mission the launch vehicles included were the Shuttle/Tug (I, R)/Kick/SEP and the Shuttle/Centaur/SEP. For the asteroid rendezvous mission all three candidate launch vehicles are used in off-loaded conditions. For each option the initial mass, the propellant mass, and the net approach mass were given as a function of flight time. Asteroid Metis is a fairly large interesting asteroid having a reddish color and a high albedo.

6. 1987 Mercury SEP Mission

Tabular data was provided for a 450-day mission to Mercury using a 20 kw SEP stage. The launch vehicle considered was a Shuttle/Tug (I, R). The values for initial mass and approach mass are given as "near optimum" due to the difficulty and expense of obtaining converged Mercury trajectories. Propulsion times of 450, 400 and 350 days were considered.

7. Space Shuttle and Planetary Missions

This white paper was prepared for the Planetary Programs Office and was used as an input to the Space Science Board Summer Study investigating the applications of the Space Shuttle.

The purpose of the white paper was to review and discuss the application of the Space Shuttle system to planetary missions, particularly during its introductory years of service, 1980-85. It was the intent to relate anticipated planetary mission requirements with candidate Shuttle-based escape stage capabilities. In addition, several specific mission point designs were detailed on the basis of a Shuttle/Centaur launch system.

The first section of the white paper presents the current mission model and the rationale related to these future plans. Section 2 includes a brief description of the Shuttle and its operations for planetary missions. Several escape-stage alternatives are presented including the Centaur, the recoverable and expendable Tugs. An escape-stage capture evaluation is presented for nine different planet, comet, and asteroid missions assuming a 20 KW solar electric propulsion (SEP) stage is available as needed. Section 3 is comprised of three mission descriptions assuming a Shuttle/Centaur launch system is used for these missions. The missions considered are: (a) 1980 Pioneer Saturn/Uranus Entry Probes, (b) 1981 Encke SEP Rendezvous, and (c) 1981/82 Mariner Jupiter Orbiters. Benefits of using the Shuttle/Centaur rather than the Titan IIID/Centaur are discussed.

8. Pioneer Saturn and Uranus Entry Probe Mission

This task was performed to provide immediate follow-up data on an alternative Pioneer/Probe mission set which had been presented to the Outer Planets Science Advisory Committee (OPSAC). The targeting flexibility was developed for the mission set: 1980 PJU, 1981 PS, and PSU with particular regard to the 1982 PSU targeting options prior to

Saturn encounter. Data was provided on swing-by radii, trip times to all targets and launch window constraints for Pioneer class missions using the Titan/Centaur/TE 364-4 launch vehicle.

9. Comet Kohoutek Flyby Mission Parameters

This task provided optimum flyby trajectory parameters for Comet Kohoutek as a function of launch date during the six months from May to November. Encounter dates occurred early in 1974 as the comet passed through its descending node after perihelion. It was noted that the trajectories presented go out as far as 1.8 AU prior to (or at) encounter, with spacecraft-earth communication distance at flyby reaching 2 AU. A plot of injected payload performance versus launch date was presented for three launch vehicles: 1) the Scout E, 2) the Delta 2914, and 3) the Atlas D/Centaur/TE 364-4. The Scout E is obviously too small a launch vehicle for sensible spacecraft payloads. A spacecraft capable of communicating with earth from a distance of up to 2 AU probably weighs at least 200 kg including science instruments. For 200 kg payload the Delta 2914 could meet Kohoutek flyby mission launch requirements until 11 August 1973; the Atlas D/Centaur/TE 364-4 could do so until 8 September.

10. Recovered Tug Earth Escape Performance

A performance graph was prepared to compare the performance of a Shuttle launched recovered Tug with a Titan/Centaur. The recovered Tug options included the addition of a Burner II and an APC kick stage individually and in combination. In all cases the performance was considerably below an expendable Tug.

11. Titan Atmosphere Workshop

The workshop was convened at Ames Research Center under the chairmanship of D. M. Hunten. At the request of NASA Headquarters, purpose was to define, as far as now possible, the atmosphere of Titan for use in the planning of future missions to that body. Titan's prominence is so recent that all the active workers could easily meet in a small room. More than half these people were actually present, and a good coverage of the appropriate disciplines was obtained.

Titan offers a unique opportunity in solar system exploration. It is the smallest known body with an atmosphere. In terms of spacecraft entry dynamics, it has the most accessible atmosphere in the solar system. It has dark reddish clouds which many workers believe are composed of organic compounds. It has the highest ratio of methane to hydrogen of all known reducing atmospheres, making an environment in some respects like that of the primitive earth at the time of the origin of life. It probably has the only surface of all the bodies beyond Mars with atmospheres that entry spacecraft can reach. In terms of planetary rotation rate, Titan's atmospheric circulation may occupy a unique niche between the dynamics of Venus and the earth. The surface temperature may be 150-200°K or warmer, and one model suggests an ocean of liquid methane and ammonia. While at the present this is the merest speculation, the presence of life on Titan is by no means out of the question.

Nearly two of the three days of the workshop were devoted to review papers, more than half of which concerned, as yet, unpublished results of Titanian studies and observations. The whole of our present knowledge of Titan was found to be clearly inadequate for engineering purposes (specifically atmospheric modeling), but it was equally clear that a vast improvement is feasible with today's observational techniques. These include ultra-violet and infrared spectroscopy, infrared and microwave radiometry, and stellar occultations. Observational and modeling techniques that have been used to study the planets have just begun to be applied to Titan. Many important properties are accessible which will yield a considerable improvement in our knowledge of Titan in the near future. Half a dozen recommendations for immediate work, both at the telescope and in the laboratory were generated by the workshop participants.

It was recognized, however, that a thorough characterization of the environment of Titan -- and, in particular, studies of the tantalizing questions of organic chemistry and surface morphology -- must await spacecraft investigations at or near Titan. With respect to mission planning, it was concluded that although the Mariner Jupiter/Saturn flyby missions, presently planned for launch in 1976, do not appear essential to the preparation of an atmospheric probe mission to Titan, the inclusion of Titan flyby objectives on the MJS missions would be most useful. It was also the consensus of the participants that the present outer planets atmospheric probe mission plan does not have sufficient emphasis for Titan. In particular, the three-mission set of Pioneer-Entry Probe missions includes Titan as a possible target of opportunity after Saturn and Uranus. A five-mission set of Pioneer-Probe's, with two launches dedicated for Titan, seems more appropriate. Questions regarding relevant probe science and sterilization were also discussed.

As editor for the Workshop, there was considerable coordination required during the meeting to obtain preliminary copies and transcripts of all presentations and discussions. This was followed by a concerted effort to compile a final draft version of the proceedings of the Workshop within a matter of weeks after the meeting. The report finally appeared as a NASA Special Publication, SP 340.

12. Inputs for Electric Propulsion Conference

Data was provided on Saturn and Encke SEP missions using both Shuttle and Titan launch vehicles. In addition, comparison charts were prepared for solar electric and ballistic flight modes to Encke. The data was presented by NASA at the Electric Propulsion Conference.

13. Saturn Orbiter Performance Curves

Earth-escape and useful orbited payload variations with flight time to Saturn were generated for the 1985 launch opportunity. The launch vehicle assumed was the Shuttle/Centaur/SPM. The SPM stage is the space propulsion module. Periapse radii of 1.6 R_s and 3 R_s were considered. Space storable retro propulsion was assumed.

14. OOS Tug Evaluation

An assessment of OOS (Orbit to Orbit) Tug options (as presented by MSFC) was performed for the Planetary Programs Division. Transition period missions were spotted with performance curves for the Growth Transtage, Growth Agena, and Growth Centaur OOS Stages. Both expendable and resuable modes were considered. For planetary missions it was concluded that the Growth Centaur was the most cost-effective OOS candidate. It also is the only OOS Tug option capable of meeting post-1984 planetary mission requirements.

15. Ballistic Encke/81 Rendezvous

Preliminary analysis of the use of gravity assist to reduce energy requirements of a ballistic multi-impulse Encke/81 rendezvous mission failed to turn up any positive results. Neither Jupiter nor Mars are properly situated for a useful swingby. It is doubtful that Venus would be of any interest due to its orbital motion relative to the transfer trajectory.

16. Comet Encke 80 Flyby /Asteroid Rendezvous Mission

A multi-target mission mode was developed which utilizes SEP to rendezvous with an asteroid after the encounter with Encke. This mode could be defined as a "no-risk" Encke flyby mission relative to

SEP technology. Launched in mid-1980, the earth-Encke transfer is all-ballistic, and SEP operation begins after comet encounter and is relied upon only to accomplish the secondary target objectives. The study was an exploratory analysis and was therefore limited in scope to a description of trajectory profile and spacecraft mass characteristics.

The pertinent conclusions from this analysis were: 1) an attractive multi-target mission alternative exists for Encke 1980 exploration; 2) SEP technology would be employed, at virtually no risk to cometary objectives, to rendezvous with an asteroid after Encke encounter; 3) of the two asteroid target studies, Eros offers the better mission profile; 4) this mission could be the maiden SEP voyage replacing the proposed SEP slow flyby if its earlier launch date should prove to be programmatically impossible; 5) in any event, many future opportunities should exist for comet flyby-asteroid rendezvous missions (e.g. Halley 1986) which are uniquely suited to SEP capabilities. Other multi-target asteroid flyby concepts have been proposed elsewhere but rendezvous is much preferred for bodies of such small dimensions. Finally, it appears that the proposed mission concept warrants further detailed analysis to verify its design and cost feasibility.

17. Pioneer Mars 1979 Mission Options

As part of its continual planning effort, the Planetary Programs Office has been developing a number of mission options for post-Viking/75 Mars exploration. For the two remaining Mars launch opportunities in this decade, i.e. 1977 and 1979, planning emphasis to date has been placed on derivatives of Viking/75 hardware. NASA's recent commitments to the development of the Space Shuttle in this same time frame could, however, reduce resources to a point where a follow-on Viking mission might not be possible until the early 1980's. If this were to happen, rather than completely abandoning the Mars opportunity in 1979, several lower cost mission concepts have been considered .

The purpose of this study was to conduct a preliminary investigation of lower cost (<\$100M) Mars missions which perform useful exploration objectives after the Viking/75 mission. As a study guideline, it was assumed that significant cost savings would be realized by utilizing Pioneer hardware currently being developed for a pair of 1978 Venus missions. This in turn led to the additional constraint of a 1979 launch with the Atlas/Centaur launch vehicle which has been designated for the Pioneer Venus missions.

Selection of science-effective Pioneer mission concepts which would follow the Viking/75 mission without competing with future Viking missions in the early 1980's was accomplished by a process of elimination. Flyby concepts, e.g. a probe/relay bus, a remote sensor platform, or an atmospheric aeronomy platform, were all rejected because of the inadequate sampling time available considering the advanced state of Mars exploration. Low cost atmospheric entry probes and rough landers were rejected because their science potential is largely redundant to Viking/75 objectives. Two concepts, using an orbiter bus platform, were identified which have both good science potential and mission simplicity indicative of lower cost. These are: a) an aeronomy/geology orbiter, and b) a remote sensing orbiter with a number of deployable surface penetrometers.

Mission A, the Aeronomy/Geology Orbiter, would perform in situ aeronomy measurements in the Martian ionosphere by using low periapse altitude ($\approx$100km) elliptical orbits. The low altitudes in the region of periapse also permit the inclusion of several remote sensing instruments capable of performing geologic surface mapping, e.g. a radar altimeter and a γ-ray spectrometer. Key mission parameters developed in this study are summarized in the Summary Table. Both the aeronomy and geology measurements would extend similar Viking entry/lander science data to a global scale. The trade-off for this capability is sterilization of the entire Pioneer orbiter spacecraft in order to meet Mars planetary quarantine requirements. Because the spacecraft passes through the upper atmosphere every orbit, its lifetime, even with periapse control, is only several years at best. The cost of this mission, excluding science, is estimated to be about \$31M (FY '74 dollars). This assumes the modification of an additional

Pioneer Venus orbiter flight article, including sterilization, for a single launch in 1979. Suitable aeronomy instruments are readily available from many earth satellite programs, some of which have already been proposed for the Pioneer Venus orbiter mission in 1978. Appropriate remote sensing geology instruments are much more questionable, especially the γ-ray spectrometer, and could require significant development. Still, a total mission cost of $40-50M dollars seems reasonable.

Mission B, the Remote Sensing/Penetrometer Orbiter would sequentially deploy a number of surface penetrometers to preselected impact sites distributed in either the northern or southern hemisphere of the planet. In addition to being a communications relay station between a deployed penetrometer and the earth, the orbiting bus could carry a complement of remote sensing instruments for orbital investigation of the Martian atmosphere and surface. Key mission parameters developed in this study are given in the Summary Table. A total of four sterilized penetrometers would be carried by a modified Pioneer Venus orbiter bus. These would be deployed one at a time from an elliptical polar orbit over a period of time as long as one Mars year. Each penetrometer would have its own deorbit motor and entry/descent system. Penetrometer design and descent velocity specification provide for a minimum penetration of 1 m in rock without destruction. During a 1-week surface lifetime each penetrometer would identify soil penetrability, search for subsurface water, and perform an elemental chemical analysis of the subsurface material at its impact site. The data collected from its instruments would be transmitted to the orbiter once each Mars day for relay back to earth. Between the four one-week penetrometer missions the orbiter could perform remote sensing measurements with its own science package. The factors of low cost, low power, low data rate, and high minimum altitudes (>1000 km) probably restrict these measurements to atmospheric studies with existing or slightly modified instruments. The scientific merit of such experiments in 1980 requires further study. The cost of this mission, excluding orbiter science, for a single 1979 launch is estimated to be about $63M. This figure includes $24M for the development and fabrication of four penetrometers (including penetrometer science), one flight spare and a PTM. Depending on the selected orbiter remote sensing experiments, total cost (excluding launch vehicle) for the Remote Sensing/Penetrometer Mission could have a range of $70-80M (FY '74 dollars).

Summary Table

SELECTED PIONEER MARS MISSION CONCEPTS

- Mission A: Aeronomy/Geology Orbiter
  - o 50-70 kg science payload
  - o Aeronomy and surface geology science instrumentation
  - o 300-350 kg orbited payload
  - o $\geq$ 100 km periapse altitude
  - o 24 hour initial orbit period
  - o 45^o orbit inclination
  - o ≈One Mars year orbit lifetime
  - o Entire spacecraft sterilized

- Mission B: Remote Sensing Orbiter/Penetrometers
  - o 40-60 kg orbiter science payload
  - o Four impact penetrometers @ 40 kg each
  - o Penetrability, water detection, and soil chemistry impact science instrumentation
  - o 500-550 kg orbited payload
  - o 1000 km periapse altitude
  - o 24.6 hour controlled orbit
  - o 90^o orbit inclination
  - o >42 year orbit lifetime
  - o ≈One week penetrometer lifetime
  - o Penetrometers sterilized

This exploratory analysis has identified and outlined at least two 1979 Mars mission concepts, based on Pioneer Venus technology and hardware, which have the potential for performing relevant post-Viking/75 science at a cost of less than $100M. Mission A, the Aeronomy/Geology Orbiter, represents a minimum development/cost mission estimated at less than $50M. Yet the broad sampling of ionospheric composition and heat balance performed by this mission would greatly expand the data base from which scientists are trying to understand the evolution of the Martian atmosphere. Further, its potential for performing global geologic mapping from low altitude, gained by sterilizing the entire spacecraft, is not possible with the present Viking orbiter design.

Mission B, the Remote Sensing/Penetrometer Mission, is a somewhat more expensive mission, with in situ surface objectives, estimated at a cost of $70-80M. This mission requires the development of high impact ($\approx$150m/sec) penetrometers for which there exists an impressive history of earth-based experience. Pioneer Venus orbiter modifications would also be more significant than for Mission A. The science highlights of this mission are a) global exploration for subsurface water and b) establishment of a basis for extension of Viking Lander geologic data to global interpretations. The orbiter has the capability to perform continued non-imaging remote sensing studies of Mars from a polar orbit. The penetrometer concept also is a viable candidate for additional missions after 1979. Besides deploying the same penetrometers to more sites, there is the potential for a penetrometer/seismometer experiment pending development of a longer life ($\approx$90 day) power source.

It is important to point out that neither of these concepts should be considered feasible on the basis of this study. Many engineering questions exist for both concepts which require further study. Indeed, the actual Pioneer Venus Orbiter spacecraft design was not known at the time this analysis was performed. Undoubtedly there are solutions for each engineering problem which can be developed in a spacecraft systems study. The important question to be answered is: "How do these solutions change the definition and cost of the missions?"

It is equally important to note that the potential role of Pioneer-class Mars missions has not been thoroughly explored by a NASA science advisory group.[1] This potential should be refined for various post-Viking/75 Mars exploration scenarios as more and better definitions of Pioneer Mars mission concepts are developed.